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Executive Summary

This report summarizes the results of the research performed at Boston University exploring the acoustics and psychoacoustics of sound localization and auditory perception in everyday situations, such as when reverberant energy degrades the stimuli reaching the listener's ears. The results of this work are unique in that little previous work has examined how environmental effects caused by reverberant sound energy impact perception in complex settings with competing sound sources.

Studies of selective attention in different sound mixtures demonstrate that spatial separation of sound sources reduces perceptual interference between sources in multiple, distinct ways. In particular, spatial separation of competing sources 1) enables detection of sound energy from a source that would otherwise be masked, 2) enhances object segregation, reducing one form of "informational masking," and 3) enhances the perceptual distinctiveness of competing objects, which enhances selective attention (reducing a second form of "informational masking"). Studies extending this work demonstrate that similar release from informational masking occurs with differences between source and interferer pitch, which both enhances object segregation and improves the efficacy of selective attention. Reflected sound energy degrades judgments of source direction, but enhances perception of source distance. Acoustic analysis of the effects of reverberation on the spatial information in the signals reaching a listener show corresponding deficits in spatial directional cues, but enhancement of features that vary with source distance. Collaborations with neurophysiologists show that many of the kinds of perceptual interference studied psychophysically have correlates in the neural responses measured in the midbrain and cortex.

Results

Work on this project encompassed numerous inter-related topics:

- 1) **selective attention** in complex acoustic scenes,
- 2) **sound localization** in rooms,
- 3) modeling and analysis of the effects of **room reverberation**,
- 4) **collaborative neuroscience** studies with a range of other scientists, and
- 5) **computational auditory scene analysis**.

Major findings in each of these areas are reviewed in turn.

1. Selective attention

An early study in this project demonstrated that spatial acoustic cues provide multiple, distinct forms of perceptual advantage when listening selectively to a complex, structured signal (here, birdsong) in the presence of competing sources. Depending on whether the main problem facing the listener is energetic masking or more central interference, there are different forms of release from masking with spatial separation of competing sources. Moreover, the largest spatial effect arises when the listener has difficulty perceptually separating target from masker. (Published in 2005 in J Acoust Soc Am [J2])

A follow-up study demonstrated that spatial release from masking that is central (rather than energetic) does not depend on the realism of the spatial cues. Equivalent amounts of spatial release from masking are obtained for very realistic cues and simple interaural difference cues that can produce percepts of sound sources within the head. This finding supports the idea that much of the central interference that arises requires only a

robust, salient feature to differentiate target from masker and thereby support selective attention. (Published in 2005 in Acta Acustica united with Acustica [J3])

A paper was published reviewing of the ways in which spatial cues reduce perceptual interference. (Published as a conference paper in 2005 [C5])

Another study of central interference (informational masking) demonstrated that random maskers interfere with perception more than fixed maskers. This study showed that the listener performs sub-optimally when central interference arises, and explored how both the slope of psychometric functions relating performance to the target-to-masker energy ratio and thresholds are affected by informational masking. (Published in 2005 in J Acoust Soc Am [J5])

As part of her dissertation research, graduate student Antje Ihlefeld performed a number of behavioral studies showing that the relationship between the relative level of the target and any interferers as well as their higher-level features determines what kind of perceptual interference dominates performance. She showed that confusions between target and masker are more important at high signal-to-noise levels while energetic masking dominates at low levels. Moreover, this work showed that the release from masking that is afforded by spatial separation between target and masker, as well as the kinds of perceptual errors that a listener makes, depend on the kind of interference that dominates performance. (Now in press in J Acoust Soc Am [J15]).

Another study by Ihlefeld demonstrated that spatial cues help listeners combat informational masking not only through enabling them to select the proper target, but by enhancing streaming (the association of syllables into a cohesive perceptual object over time scales on the order of tens to hundreds of ms). (Provisionally accepted for J Acoust Soc Am [J16])

She also demonstrated that listeners can select a target source out of a mixture using intensity cues in much the same way that they can use spatial cues. (Published as a conference paper in 2007 [C10]).

Most of the studies mentioned above are “supra-threshold” tasks, requiring a listener to extract meaning from the spectro-temporal content of a sound source. However, many of the past studies exploring spatial unmasking have focused on threshold tasks, looking at when listeners can simply detect the presence of a signal. Work done in collaboration with colleagues in other laboratories at Boston University explored whether there distinct ways in which spatial cues can contribute to detection that depend on the relative content of target and masker, paralleling the different contributions of spatial cues to supra-threshold tasks. This study found evidence that spatial cues do have different roles even in detection tasks, depending on whether the dominant form of perceptual interference is from energetic or informational masking. (Now in press in J Acoust Soc Am [J15])

Two recent papers explored the detrimental effects of hearing impairment on the ability to selectively attend to a target sound in a sound mixture. These studies suggest that hearing impairment degrades the basic acoustic cues that enable object formation and the memory storage of the target, thereby interfering with selective attention. (Published as conference papers in 2007 [C11 and C12])

Many of these ideas about how the ways in which different forms of perceptual interference arise are discussed in a recent review article. This review explains how

“informational masking” can arise due to failures either in object formation and/or in object selection. (Published in 2008 in Trends Cog Sci [J11])

Another recent book chapter summarizes the importance of considering how auditory scene analysis influences auditory perception and the ability to selectively extract information about one sound source when designing an auditory display. (Published in 2008 [B1])

2. Sound localization

Analysis of ongoing spatial cues showed that the degradation of spatial cues caused by reverberation can be thought of as noise that causes variation in the “true” (anechoic) spatial cues) over time. As the D/R decreases, the variations in spatial cues over time become more rapid and larger in magnitude. (Published in 2006 in Int J Audiology [J6])

Unlike perception of source direction, perception of source distance is enhanced by reverberant energy. However, listeners must build up some expectation of the level of the reverberation in order to know how to map distance cues to actual distances. This “learning” of the reverberation was demonstrated by showing that accuracy of distance judgments is enhanced when the reverberation was constant over a block of trials, enabling listeners to build up expectations, compared to when it varied from trial to trial. (Published as a conference paper in 2004 [C1])

While reverberant energy is one of the most robust distance cues, many other acoustic features may convey auditory distance information. Monaural and binaural simulations actually lead to similar distance accuracy, arguing that changes in binaural cues with distance contribute little to distance perception in rooms. (Published as a conference paper in 2004 [C13])

3. Room reverberation

In order to study the perceptual consequences of realistic room reverberation on perception, it is important to be able to carefully control the signals reaching the listener, yet have the signals reaching the listener like those that would happen in an everyday setting. Excellent control can be achieved along with realism by simulating realistic settings under headphones. However, in order to do this, one either needs to measure or model the transfer functions from source to listener ears.

In one study, impulse responses in a room were repeatedly measured as a function of the source-to-listener angle and direction in an ordinary classroom. Analysis of the impulse responses showed that room reverberation causes systematic degradations of spatial cues. The degree to which monaural spatial cues are degraded depends on the direct-to-reverberant energy ratio (D/R), which decreases with increasing source distance (due to decreasing direct sound energy) and at the far ear as the source lateral angle increases (due to head shadow). The fidelity of binaural cues depends on the D/R at the worse acoustic ear, and thus decreases with source distance and with source laterality. (Published in 2005 in J Acoust Soc Am [J1])

Measurement is slow and time consuming. Thus, methods for simulating realistic impulse responses were undertaken to test the feasibility of modeling the impulse responses. New mathematical methods for solving the wave equation were found, many of which proved to give exceptional accuracy along with large computational savings, compared to conventional methods. However, none of these approaches proved to be practical for generating realistic impulse responses for use in psychoacoustic testing

due to the complexity of the computational demands. (Published as conference papers in 2004 [C3] and 2007 [C14], in 2005 in J Acoust Soc Am [J4], and under revision for Comp Meth Appl Mech Eng [J17])

The mathematical approaches developed for simulating realistic reverberation lead to a collaboration to use similar methods to model the acoustic characteristics of the head of gerbils, an animal model used in behavioral and neurophysiological studies of sound localization. (Published in 2008 in Acta Acustica united with Acustica [J10])

Interest in the perceptual consequences of reverberation on perception also lead to a collaboration with a visiting scholar from Korea. This project demonstrated that the perceived quality of audio reproduction systems is predicted much more accurately when one takes into account the effects of the listening environment on the signals reaching the listener. In particular, by considering how the room reverberation alters interaural correlation between the signals reaching the listener and understanding how spatial perception depends on interaural correlation and other interaural parameters, better prediction of sound quality is achieved. (Published as a conference paper [C9] and in 2008 in J Aud Eng Soc [J13])

Finally, a brief review of the perceptual consequences of including reverberation in auditory displays summarized many of the perceptual studies performed. This review concluded that directional accuracy was degraded slightly but distance perception enhanced by including reverberation. However, the review also pointed out that very little is known about how room reverberation impacts perception of source content, rather than source location, and that reverberation would undoubtedly have important consequences on this aspect of perception. (Published as a conference paper in 2004 [C2])

4. Collaborative neuroscience

In order to understand and model perceptual effects, it is critical to understand the underlying neural mechanisms. A number of collaborations have grown out of this interest, exploring how neural responses reflect perceptual results.

A collaboration with researchers at the Martinos Imaging Center (part of Massachusetts General Hospital) using a combination of MEG and fMRI recording showed that the brain areas involved in processing spatial attributes of sound (“where”) differ from those involved in processing non-spatial attributes (“what”). (Published in 2006 in Proc Nat Acad Sci [J7])

In parallel with human studies exploring how human listeners cope with different forms of perceptual interference when trying to identify different zebra finch calls (see [J2]), we performed studies measuring how competing sound sources degraded the information encoded in neural spike trains from individual neurons in the forebrain of anesthetized zebra finch. The study also showed that the ability of behaving zebra finches, trained to discriminate the same zebra finch songs, closely matched the performance of a classification algorithm that measured the information in the spike trains from individual neurons presented with the same sound mixtures. (Published in a conference paper in 2006 [C6] and in 2007 in Nat Neurosci [J8]).

A follow-up study exploring bird behavior found significant differences in how different bird species learned to perform the discrimination of different songs. (Published in 2008 in Beh Proc [J9])

A study in the midbrain of the cat (inferior colliculus) showed parallels between the behavioral importance of spatial separation between competing sound sources and the improvements in how single neurons encoded the presence of a competing sound source with spatial separation. (Published as a conference paper in 2004 [C4])

In the same midbrain neurons, the encoding of source angle is degraded by realistic reverberation. Moreover, this degradation in the neural information parallels the degradations of human abilities to judge source direction. (Published as a conference paper in 2006 [C7])

5. Computational auditory scene analysis

A collaborative effort conducted with computational researchers at Mitsubishi Electric Research Laboratory lead to a number of studies exploring new algorithms for separating a sound mixture into constituent sound sources. This work, while not part of the original goals of the project, ultimately can inform our understanding of the heuristics by which the human selectively attends to one source, a feat that requires separation of the sources.

By building up knowledge of the sound source characteristics and finding solutions in which sound elements can be added, but not subtracted (non-negative factorization), excellent separation can be achieved. (Published as conference papers in 2006 [C8] and in 2008 in Comp Intell Neurosci [J12])

Adding an additional constraint that favors a sparse solution (i.e., a parsimony constraint) along with a non-negative factorization produces even better source separation. (Published as conference papers in 2007 [C15, C16, and C17])

Personnel

The personnel supported in whole or in part by this project were:

Principal Investigator: Barbara Shinn-Cunningham (Boston University)

Collaborators: Steve Colburn (Boston University) and Nat Durlach (Boston University and the Massachusetts Institute of Technology)

Post-doctoral Associates: Virginia Best and Erick Gallun

Graduate Students: Scott Bressler (Boston University, BME), Antje Ihlefeld (Boston University, CNS), Kosuke Kawakyu, (MIT, SHBT), Ross Maddox (Boston University, BME), Yusuke Naka (Boston University, AME), Erol Ozmeral (Boston University, BME), Satyavarta (Boston University, CNS), Madhu Shashanka (Boston University, CNS), and Dali Wang (Boston University, BME)

Undergraduates: Sarah Chu (MIT), Eric Larson (Michigan State), Justin Kiggins (Arizona)

Publications

Journal Articles (13 published, 2 in press, 1 provisionally accepted, 1 under revision)

[J1] Shinn-Cunningham, BG, N Kopco, and T. Martin (2005). "Localizing nearby sound sources in a classroom: binaural room impulse responses", *Journal of the Acoustical Society of America* 117, 3100-3115.

[J2] Best, V, E Ozmeral, F Gallun, K Sen, and BG Shinn-Cunningham (2005). "Spatial unmasking of birdsong in human listeners: Energetic and informational factors" *Journal of the Acoustical Society of America*, 118(6), 3766-3773.

- [J3] Shinn-Cunningham, BG, A Ihfeld, E Larson and Satyavarta (2005). "Top-down and bottom-up influences on spatial unmasking," *Acta Acustica united with Acustica*.
- [J4] Naka, Y, A Oberai, and BG Shinn-Cunningham (2005). "Acoustic eigenvalues of rectangular rooms with arbitrary wall impedances using the interval Newton/generalized bisection method," *Journal of the Acoustical Society of America*, 118(6), 3662-3671.
- [J5] Durlach, NI, CR Mason, FJ Gallun, BG Shinn-Cunningham, HS Colburn, and G Kidd, Jr. (2005). "Informational masking for simultaneous nonspeech stimuli: Psychometric functions for fixed and randomly mixed maskers," *Journal of the Acoustical Society of America*, 118(4), 2482-2497.
- [J6] Colburn, HS, BG Shinn-Cunningham, G Kidd, and N Durlach (2006). "The perceptual consequences of binaural hearing," *International Journal of Audiology*, 45, S34-S44.
- [J7] Ahveninen, J, IP Jaaskelainen, T Raji, G Bonmassar, S Devore, M Hamalainen, S Levanen, FH Lin, M Sams, BG Shinn-Cunningham, T Witzel, JW Belliveau (2006). "Task-modulated 'what' and 'where' pathways in human auditory cortex," *Proceedings of the National Academy of Science*, 103, 14608-14613.
- [J8] Narayan, R, V Best, EJ Ozmeral, BG Shinn-Cunningham, and K Sen (2007). "Cortical interference effects in the cocktail party problem," *Nature Neuroscience*, 10(12), 1601-1607 [feat. in Faculty of 1000 Biology: evaluations for Narayan R et al *Nat Neurosci* 2007 Dec 10 (12) :1601-7
<http://www.f1000biology.com/article/id/1098200/evaluation>].
- [J9] Dent, ML, TE Welch, EM McClaine, and BG Shinn-Cunningham (2008). "Species differences in the categorization of acoustic stimuli by birds," *Behavioral Processes*, 77, 184-190.
- [J10] Grace, SM, E Quaranta, BG Shinn-Cunningham, and HF Voigt (2008). "Simulation of the head-related transfer function for gerbils using a boundary element method," *Acta Acustica United with Acustica*, 94, 310-320.
- [J11] Shinn-Cunningham, BG (2008). "Object-based auditory and visual attention," *Trends in Cognitive Sciences*, 12, 182-186.
- [J12] Shashanka, M, B Raj, P Smaragdis (2008). "Probabilistic latent variable models as non-negative factorizations," *Computational Intelligence and Neuroscience*, Special Issue on Advances in Non-Negative Matrix and Tensor Factorizations.
- [J13] Choi, IY, BG Shinn-Cunningham, SB Chon, and K-M Sung (2008). "Objective Measurement of Perceived Auditory Quality in Multi-channel Audio Compression Coding Systems," *Journal of the Audio Engineering Society*, 56, 3-17.
- [J14] Ihfeld, A and BG Shinn-Cunningham (2008). "Spatial release from energetic and informational masking in a selective speech identification task," *Journal of the Acoustical Society of America*, in press.
- [J15] Gallun, FJ, NI Durlach, HS Colburn, BG Shinn-Cunningham, V Best, CR Mason, and G Kidd, Jr. (2008). "The extent to which a position-based explanation accounts for binaural release from informational masking," *Journal of the Acoustical Society of America*, in press.
- [J16] Ihfeld, A and BG Shinn-Cunningham (provisionally accepted). "Disentangling the effects of spatial cues on selection and formation of auditory objects," *Journal of the Acoustical Society of America*.

- [J17] Naka, Y, A Oberai, and BG Shinn-Cunningham (under revision). "Optimal space-time finite difference schemes for the second-order scalar wave equation," Computer Methods for Applied Mechanics and Engineering.

Conference papers (17)

- [C1] Kopco, N, M Schoolmaster, and BG Shinn-Cunningham (2004). "Learning to judge distance of nearby sounds in reverberant and anechoic environments," Joint Congress of CFADAGA '04, 22-25 March 2004.
- [C2] Shinn-Cunningham, BG (2004). "The perceptual consequences of creating a realistic, reverberant 3-D audio display," Proceedings of the International Congress on Acoustics, Kyoto, Japan, 4-9 April 2004.
- [C3] Naka, Y, A Oberai, and BG Shinn-Cunningham (2004). "The finite element method with the Dirichlet-to-Neumann map for sound-hard rectangular rooms," Proceedings of the International Congress on Acoustics, Kyoto, Japan, 4-9 April 2004.
- [C4] Lane, CC, N Kopco, B Delgutte, BG Shinn-Cunningham, and HS Colburn (2004). "A cat's cocktail party: Psychophysical, neurophysiological, and computational studies of spatial release from masking," in Auditory Signal Processing: Physiology, Psychoacoustics, and Models, D Pressnitzer, A de Cheveigne, S McAdams, and L Collet (eds.), Springer Verlag, 405-413 (book chapter that finally appeared, funded in part by preceding AFOSR grant).
- [C5] Shinn-Cunningham, BG (2005). "Influences of spatial cues on grouping and understanding sound," Proceedings of the Forum Acusticum, 29 August – 2 September 2005, Budapest, Hungary [invited talk].
- [C6] Shinn-Cunningham, BG, V Best, ML Dent, FJ Gallun, E McClaine, R Narayan, E Ozmeral, and K Sen (2006). "Behavioral and neural identification of birdsong under several masking conditions," Proc. of the International Symposium on Hearing, Cloppenburg, Germany, 164-170 [peer-reviewed].
- [C7] Devore, S, A Ihlefeld, BG Shinn-Cunningham, and B Delgutte (2006). "Neural and behavioral sensitivities to azimuth degrade with distance in reverberant environments," Proc. of the International Symposium on Hearing, Cloppenburg, Germany, 382-388 [peer-reviewed].
- [C8] Smaragdis, P, B Raj, and M Shashanka (2006). "A probabilistic latent variable model for acoustic modeling," Advances in models for acoustic processing workshop, NIPS 2006.
- [C9] Choi, IY, BG Shinn-Cunningham, SB Chon, and K-M Song (2007). "Prediction of perceived quality in multi-channel audio compression coding systems," Proceedings of the Audio Engineering Society 30th International Conference, Saariselka, Finland, 15-17 March 2007.
- [C10] Ihlefeld, I, S Chu, and BG Shinn-Cunningham (2007). "Attending to space or intensity modulates spatial release from informational masking," Proceedings of the DAGA (German Acoustical Society), Stuttgart, Germany, 19-22 March [invited talk].
- [C11] Shinn-Cunningham, BG (2007). "Why hearing impairment may degrade selective attention," Proceedings of the International Symposium on Auditory and Audiological Research, Helsingør, Denmark, 29-31 August [invited talk].
- [C12] Best, V, N Marrone, CR Mason, G Kidd, Jr., and BG Shinn-Cunningham (2007). "Do hearing-impaired listeners benefit from spatial and temporal cues in a complex

auditory scene?," Proceedings of the International Symposium on Auditory and Audiological Research, Helsingør, Denmark, 29-31 August.

- [C13] Kopco, N, V Best, and BG Shinn-Cunningham (2007). "Simulating distance cues in virtual reverberant environments," Proceedings of the International Congress on Acoustics, Madrid, Spain, 2-7 September [invited talk].
- [C14] Naka, Y, A Oberai and Shinn-Cunningham, BG (2007). "Optimal space-time finite difference schemes for experimental booth design," Proceedings of the International Congress on Acoustics, Madrid, Spain, 5-7 September [invited talk].
- [C15] Shashanka, M, B Raj, and P Smaragdis (2007). "Sparse overcomplete decomposition for single channel speaker separation," IEEE International Conference on Audio and Speech Signal Processing, Honolulu, Hawaii, USA. 15-20 April.
- [C16] Shashanka, M, B Raj, and P Smaragdis (2007). "Sparse overcomplete latent variable decomposition of counts data," Neural Information Processing Systems Conference (NIPS), Vancouver, Canada, December.
- [C17] Smaragdis, P, B Raj, and M Shashanka (2007). "Sparse and shift-invariant feature extraction from non-negative data," IEEE Intl Conf on Acoustics, Speech and Signal Processing, Las Vegas, Nevada, April.

Book Chapters (1)

- [B1] Peres, SC, V Best, D Brock, C Frauenberger, T Hermann, JG Neuhof, L Valgerdaeur, BG Shinn-Cunningham, and T Stockman (2008). "Auditory interfaces," In HCI Beyond the GUI: The Human Factors in Non-Traditional Interfaces, P Kortum (ed), Morgan Kaufman.

Interactions/Transitions

a. Participation/presentations at meetings, conferences, seminars, etc.

Presentations (51)

- Kawakyu, K and BG Shinn-Cunningham (2004). "Responses of a simple MSO population model to realistic reverberant signals," Mid-Winter Meeting of the Association for Research in Otolaryngology, 21-26 February 2004.
- Devore, S and BG Shinn-Cunningham (2004). "Can room reverberation be modeled as statistical interaural decorrelation?," Mid-Winter Meeting of the Association for Research in Otolaryngology, 21-26 February 2004.
- Ihlefeld, A, and BG Shinn-Cunningham (2004). "Extracting sound location cues in reverberant space: Short-term interaural level differences in a classroom ," 8th International Conference on Cognitive and Neural Systems, Boston, MA, 19-24 May 2004.
- Schoolmaster, M, N Kopco, and BG Shinn-Cunningham (2004). "Auditory distance perception in fixed and varying simulated acoustic environments," Journal of the Acoustical Society of America (in press).
- Ihlefeld, A, and BG Shinn-Cunningham (2004). "Effect of source location and listener location on ILD cues in a reverberant room," Journal of the Acoustical Society of America.
- Shinn-Cunningham, BG (2004). "Spatial processing and spatial perception in everyday settings," talk presented at the Workshop on Auditory Processing of Vocalizations and other Complex Sounds, Cold Spring Harbor, New York, 24 March 2004.

- Shinn-Cunningham, BG (2004). "Localizing sound in everyday life," talk presented at the Neuromuscular Research Center seminar series, Boston University, 15 April 2004.
- Shinn-Cunningham, BG (2004). "Bottom-up and top-down influences of auditory spatial processing," talk presented at the Summer School on Object Formation in Audition and Vision: Bottom-up and Top-Down Processing, Oldenburg, Germany, 18-22 August 2004.
- Shinn-Cunningham, BG (2004). "Spatial attention and source segregation," talk presented at the Workshop on Source Segregation, Hanse Institute, Delmenhorst, Germany, 22-24 August 2004.
- Shinn-Cunningham, BG (2004). "How humans cope in natural settings," Workshop on Speech Separation and Comprehension in Complex Acoustic Environments by Humans and Machines, Montreal, Canada, 4-7 November 2004 [invited presentation].
- Shinn-Cunningham, BG (2004). "Human adaptation to altered sound," Workshop on Speech Separation and Comprehension in Complex Acoustic Environments by Humans and Machines, Montreal, Canada, 4-7 November 2004 [invited presentation].
- Shinn-Cunningham, BG (2004). "Acoustic source separation in the brain: How we use two ears," talk presented at the University of New Hampshire College of Engineering and Physical Sciences Frontiers lecture series, Durham, NH, 6 December 2004.
- Shinn-Cunningham, BG, A Ihlefeld, Satyavarta, and E Larson (2004). "Spatial auditory attention," First Indo-American Frontiers of Science Symposium sponsored by the National Academies of Science, Bangalore, India, 8-10 January 2005.
- Shinn-Cunningham, BG (2005). "Understanding sound in the complex, everyday world," talk presented at 1) the Tata Institute for Fundamental Research, Mumbai, India, 12 January 2005; 2) the Indian Institute of Technology, Mumbai, India, 13 January 2005; the National Brain Research Center, New Delhi, India, 14 January 2005.
- Ihlefeld, A, E Larson, and BG Shinn-Cunningham (2005). "Spatial unmasking at a spectrally sparse cocktail party," Mid-Winter Meeting of the Association for Research in Otolaryngology, New Orleans, LA, 19-24 February 2005.
- Ozmeral, E, V Best, F Gallun, K Sen, and BG Shinn-Cunningham (2005). "Identifying a bird in a chorus: How target and masker statistics influence spatial unmasking," Mid-Winter Meeting of the Association for Research in Otolaryngology, New Orleans, LA, 19-24 February 2005.
- Ihlefeld, A, and BG Shinn-Cunningham (2005). "How natural environments alter spatial information in acoustic cues," Computational and Systems Neuroscience, Salt Lake City, UT, 17-20 March 2005.
- Kawakyu, K, and BG Shinn-Cunningham (2005). "Theoretical importance of temporal integration for sound localization in everyday environments," Computational and Systems Neuroscience, Salt Lake City, UT, 17-20 March 2005.
- Satyavarta and BG Shinn-Cunningham (2005). "Contribution of binaural mechanisms to spatial unmasking," Computational and Systems Neuroscience, Salt Lake City, UT, 17-20 March 2005.
- Shinn-Cunningham, BG (2005). "The problem of separating and localizing sound objects," Workshop on Auditory Processing: Localization and Separation,

(Computational and Systems Neuroscience), Snowbird, UT, 22 March 2005 [invited talk].

Naka, Y, and BG Shinn-Cunningham (2005). "The finite element method with the Dirichlet-to-Neumann method for rectangular rooms with impedance walls," *Journal of the Acoustical Society of America*, 117, 2580.

Kopco, N and BG Shinn-Cunningham (2005). "Spatial release from masking for amplitude modulated and non-modulated noise stimuli," *Journal of the Acoustical Society of America*, 117, 2396.

Narayan, R, V Best, E Ozmeral, BG Shinn-Cunningham and K Sen (2005). "Neural discrimination of complex stimuli in the presence of masking sounds," to be presented at the Annual Meeting of the Society for Neuroscience, Washington, DC, 12-16 November.

Ozmeral, E, V Best, and BG Shinn-Cunningham (2006). "Simple visual cues enhance the identification of target sounds in complex auditory scenes," Annual Meeting of the Australian Neuroscience Society, Sydney, Australia, 31 January – 3 February 2006.

Ozmeral, E, V Best, and BG Shinn-Cunningham (2006). "Enhanced target identification in a complex auditory scene via visual cueing," Mid-Winter Meeting of the Association for Research in Otolaryngology, Baltimore, MD, 5-9 February 2006.

Shashanka, M, S Nasser, and BG Shinn-Cunningham (2006). "The role of fundamental frequency in segregating and understanding a talker competing with another talker in a reverberant setting," Mid-Winter Meeting of the Association for Research in Otolaryngology, Baltimore, MD, 5-9 February 2006.

Ihlefeld, A and BG Shinn-Cunningham (2006). "Listening strategies affect the benefit of spatial separation in informational masking," Mid-Winter Meeting of the Association for Research in Otolaryngology, Baltimore, MD, 5-9 February 2006.

Shinn-Cunningham, BG (2006). "Spatial auditory attention," *Journal of the Acoustical Society of America*, 119, 3416, [invited].

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Ihlefeld, A S Sarwar, and BG Shinn-Cunningham (2006). "Spatial uncertainty reduces the benefit of spatial separation in selective and divided listening," *Journal of the Acoustical Society of America*, 119, 3417.

Kalluri, S, BG Shinn-Cunningham, C Eiler, and B Edwards (2006). "Interaction of hearing-aid compression with spatial unmasking," International Hearing Aid Research Conference, Lake Tahoe, August.

Ahveninen, J, IP Jääskeläinen, T Raij, G Bonmassar, S Devore, M Hämäläinen, S. Levänen, FH Lin, M Sams, BG Shinn-Cunningham, T Witzel, JW Belliveau (2006). "Feature-specific selective attention modulates the 'what' and 'where' pathways in human auditory cortex," Annual Meeting of the Society for Neuroscience, Atlanta, 14-19 October.

Shinn-Cunningham, BG, M Shashanka, and S Bressler (2006). "Separating and understanding a talker from a mixture in reverberant spaces," *Journal of the Acoustical Society of America*, 120, 3323 [invited talk].

Ozmeral, E, P Zutshi, V Best, and BG Shinn-Cunningham (2006). "Spectrotemporal structure influences spatial release from informational masking in reverberant settings," *Journal of the Acoustical Society of America*, 120, 3126.

- Naka, Y, A Oberai, and BG Shinn-Cunningham (2006). "Optimal dispersion/dissipation-error finite-difference time-domain method for room impulse response simulation," *Journal of the Acoustical Society of America*, 120, 3010.
- Dent, M, E McClaine, BG Shinn-Cunningham, V Best, E Ozmeral, FG Gallun, K Sen, and R Narayan (2006). "An avian cocktail party: Masking and unmasking in birds," *Journal of the Acoustical Society of America*, 120, 3152.
- Delgutte, B, BG Shinn-Cunningham, S Devore, and A Ihlefeld (2007) "Neural and psychophysical studies of spatial hearing in realistic acoustic environments," Mid-Winter Meeting of the Association for Research in Otolaryngology, Denver, CO, 10-15 February.
- Gallun, FJ, NI Durlach, HS Colburn, BG Shinn-Cunningham, V Best, A Ihlefeld, CR Mason, and G Kidd, Jr. (2007) "Binaural release from masking for a tone in noise and in multitone maskers," Mid-Winter Meeting of the Association for Research in Otolaryngology, Denver, CO, 10-15 February.
- Dent, ML, EM McClaine, BG Shinn-Cunningham, V Best, E Ozmeral, R Narayan, FJ Gallun, and K Sen (2007) "Spatial unmasking of birdsong by budgerigars and zebra finches," Mid-Winter Meeting of the Association for Research in Otolaryngology, Denver, CO, 10-15 February.
- Bressler, S and BG Shinn-Cunningham (2007). "The effects of pitch and spatial separation on informational masking in reverberant acoustic environments," 11th International Conference on Cognitive and Neural Systems, 16-19 May.
- Shinn-Cunningham, BG (2007). "The complexity of everyday listening," Fourth International Oticon Conference, Cancun, Mexico, 11-14 May [invited plenary speaker].
- Shinn-Cunningham, BG (2007). "Informational masking and spatial hearing," Third International Forum for Hearing Aid Developers, Oldenburg, Germany, 28-29 June [invited plenary speaker].
- Shinn-Cunningham, BG (2007). "Sound and space," Boston Colloquium for Philosophy of Science, Boston, MA, 19 February.
- Shinn-Cunningham, BG (2007). "What good is spatial hearing, anyhow?" University of Connecticut Neuroscience Colloquium, 1 March.
- Shinn-Cunningham, BG (2007). "Adding auditory attention to a neuromorphic system," Neuromorphic Engineering Workshop, Sardinia, Italy, 14 April [invited participant].
- Shinn-Cunningham, BG (2007). "Informational masking and auditory attention" Biophysics Colloquium, Oldenburg, Germany, 27 June.
- Shinn-Cunningham, BG (2007). "Auditory attention," Telluride Neuromorphic Engineering Workshop, Telluride, Colorado, July 2006 [invited participant].
- Shinn-Cunningham, BG (2007). "Divide and conquer: Auditory attention in complex scenes," Kresge Hearing Research Center Colloquium, University of Michigan, Ann Arbor, MI, 2 August.
- Shinn-Cunningham, BG (2007). "Why hearing impairment may degrade selective attention," Boston University Hearing Research Center Seminar, Boston, MA , 28 September.
- Shinn-Cunningham, BG (2007). "Influences of object formation on perception," Novartis Workshop on Auditory Objects, London, United Kingdom, 1-2 October [invited participant].

Conference Organization (15)

Chair, “Psychological and Physiological Acoustics” session, meeting of the Acoustical Society of America, 24-28 May 2004.

Publicity Chair, International Conference on Auditory Display 2004, Sydney, Australia, 6-9 July 2004

Member, Program Committee, International Symposium on Non-visual & Multimodal Visualization, London, United Kingdom, 14-16 July 2004

Member, Technical Committee, ISCA Tutorial and Research Workshop on Statistical and Perceptual Audio Processing, Jeju, Korea, 2-3 October 2004

Organizer and chair, special session on “Combating Reverberation,” Workshop on Speech Separation and Comprehension in Complex Acoustic Environments by Humans and Machines, Montreal, Canada, 4-7 November 2004

Chair, Graduate student and post-doctoral associate fellowship committee, Workshop on Speech Separation and Comprehension in Complex Acoustic Environments by Humans and Machines, Montreal, Canada, 4-7 November 2004

Member, Organizing Committee, Indo-American Frontiers of Science Symposium sponsored by the National Academies of Science, Bangalore, India, 6-8 January 2005

Co-organizer (with Barak Pearlmutter), Workshop on “Auditory Processing: Localization and Separation,” held in conjunction with the Computational and Systems Neuroscience meeting, Snowbird, Utah, 21-22 March 2005.

Co-organizer (with Russ Shilling), special session on “Conveying Emotion and Information with Sound,” VR International Conference (part of Human-Computer Interaction International 2005), Las Vegas, Nevada, 22-27 July 2005.

Co-organizer (with Shihab Shamma), Workshop on “Difficult Issues in Auditory Scene Analysis,” held in conjunction with the Computational and Systems Neuroscience meeting, Park City, Utah, 8-9 March 2006.

Co-organizer (with Earl Miller), “CELEST Workshop on Auditory and Visual Attention,” held in conjunction with the International Conference on Cognitive and Neural Systems, Boston, Massachusetts, 17 May 2006.

Chair, “Binaural Hearing (III)” session, 2006 International Symposium on Hearing, Cloppenburg, Germany, 17-23 August 2006.

Co-organizer (with Virginia Best), special session on “Displaying auditory information,” International Congress on Acoustics, Madrid, Spain, 2-7 September 2007.

Co-organizer (with Matthiew Levandier), special session on “Speech in rooms,” Acoustical Society of America, Paris, France, 29 June – 4 July 2008.

Program Committee Member, Biennial National Center for Rehabilitative Auditory Research Conference, Portland, OR, fall 2009.

b. Consultative and advisory functions to other laboratories and agencies

We provided birdsong recordings to DiLiang Wang of Ohio State University for his work on machine algorithms for source segregation.

We have developed an in-depth collaboration with Asst. Prof. Kamal Sen (Biomed. Eng., Boston University) and his graduate student Rajiv Narayan, to gather physiological recordings in Zebra Finch forebrain areas in response to the bird songs embedded in different maskers. These studies are parallel to the human psychophysical studies we are undertaking within the scope of the current project, and show that the neural interference caused by a steady-state masker is fundamentally different from the kind of neural interference caused by a masker that is qualitatively similar to the target songs (a birdsong chorus). This collaboration resulted in a publication in Nature Neuroscience.

We supplied Asst. Prof. Micheal Dent (Buffalo) with the same bird song targets and masker signals, to enable her to train both Zebra Finches and Budgies to do parallel avian psychophysics examining the effect of spatial unmasking on birdsong identification by song birds. She has already succeeded in training multiple birds to perform the classification in quiet, and is proceeding to begin gathering data in noise.

We collaborated with Asst. Prof. Assad Oberai (formerly of AME, Boston University; now at Rennselear Polytechnic Institute) on the work in room-acoustics modeling.

We collaborated with researchers at the Martinos imaging center to study spatial and non-spatial attention. We contributed our expertise on spatial simulation and provided them with our measured head-related transfer functions for their studies, which resulted in a publication in PNAS.

We collaborated with Prof. Bertrand Delgutte and graduate student Sasha Devore of MIT to explore the relationship between behavioral and physiological responses to reverberant stimuli.

c. Transitions

none

New Discoveries, Inventions, or Patent Disclosures

none

Honors / Awards

Selected participant, US-Indo Frontiers of Science Symposium sponsored by the National Academies of Science, Bangalore, India, 6-8 January 2005

Appointed Member, Tutorials Committee, Acoustical Society of America, 2005-2008, 2008-2011

Appointed member, AUD study section, National Institutes of Health, 2006-2010

Invited to become Associate Editor of the Journal of the Acoustical Society of America (turned down due to other commitments), 2006

Appointed Member, Association for Research in Otolaryngology Diversity and Minority Affairs Committee, 2006-2009

Appointed Member, Public Relations Committee, Acoustical Society of America, 2007-

Appointed Member, Public Relations Committee, Acoustical Society of America, 2007-

Appointed Member, DARPA study on "The sense of the firefight," 2007-2008

Honorary Member, Editorial Board, International Journal of BioSciences and Technology, 2008-

Invited Keynote Speaker, Oticon Hearing Aid company annual meeting, Cancun, Mexico, May 2007

Invited Plenary Speaker, Third International Forum for Hearing Aid Developers, Oldenburg, Germany, June 2007

Invited Plenary Speaker, International Hearing Aid Conference, Lake Tahoe, CA, August 2008

Semi-Finalist, inaugural NSSEFF competition, 2008